June 25, 2001

Dr. Lori M. Fussell
Institute of Science, Ecology and the Environment
2570 Teton Pines Drive
Wilson, WY 83014

Dear Dr. Fussell:

Enclosed you will find the final report for SwRI Project No. 04294 entitled “Emission Testing for the 2001 Clean Snowmobile Challenge.” We have enjoyed working with you on this project, and hope we can be involved again in the future. Please call me if you have any questions about this report. I can be reached at (210) 522-2649 (phone), (210) 522-3950 (FAX), or by email at jjwhite@swri.org.

Sincerely,

Jeff J. White
Manager, Certification, Audit, and Compliance
Department of Emissions Research
Automotive Products and Emissions Research Division

c: Howard Haines, Montana Department of Environmental Quality
Jim Carroll, SwRI

SwRI 08.04294

EMISSION TESTING FOR THE 2001 CLEAN SNOWMOBILE CHALLENGE

By

Jeff J. White

FINAL REPORT

Prepared for

Institute of Science, Ecology and the Environment
2570 Teton Pines Drive
Wilson, Wyoming 83014

June 2001

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TO: Institute of Science, Ecology and the Environment
2570 Teton Pines Drive
Wilson, WY 83014

ATTN: Dr. Lori Fussell
Executive Director

SUBJECT: Final Report, "Emission Testing for the 2001 Clean Snowmobile Challenge," SwRI Project 04294.

I. INTRODUCTION

The first SAE Clean Snowmobile Challenge (CSC) was held in Jackson Hole, Wyoming in late March of 2000. It drew public attention to environmental issues associated with recreational products such as snowmobiles, and encouraged development of novel solutions through this SAE-sponsored student competition. While much good information was obtained, one area needing improvement was emissions measurement. In 2000, snowmobile emissions were measured using a drive-by infrared-type device. While this provided a rough indication of emission levels, more accurate data was desired to better reflect progress in reducing emissions.

For this year's competition, Southwest Research Institute (SwRI) assembled the equipment necessary to provide brake-specific emissions measurement on-site. A truck-mounted mobile unit was outfitted with laboratory-grade instrumentation for measurement of HC, CO, NO_x, CO_2, and O_2. A snowmobile chassis dynamometer was used to load the engines. A modified version of the five mode snowmobile test cycle, as developed by SwRI for the International Snowmobile Manufacturers Association (ISMA), was used for testing.

Fourteen teams entered snowmobiles in the completion, employing a range of technologies, including both 2- and 4-stroke designs and aftertreatment. A detailed summary of competition emission results is included, along with a discussion of the effectiveness of various design approaches in reducing emissions.

II. THE CLEAN SNOWMOBILE CHALLENGE 2001

The SAE Clean Snowmobile Challenge 2001 was held in Jackson Hole, Wyoming from March 25-30, 2001. The first part of the competition, including the emissions testing, was conducted at Flagg Ranch Resort, which is north of Jackson, just south of Yellowstone National Park. Later parts of the competition were held in Grand Teton National Park, at Jackson Hole Mountain Resort, and at Snow King Resort.

Teams participating in CSC 2001 are listed in Table 1. Engine configurations, as run at the event, are also listed.

TABLE 1. SCHOOLS AND ENGINE DESCRIPTIONS

School	Engine
Clarkson University	Honda CBRT 929 EFI 4-stroke with catalyst
Colorado School of Mines	Honda CBR 600 F-4 carb. 4-stroke with TWC catalyst
Colorado State Univ. (CSU)	Supercharged reverse uniflow 600 cc Polaris 2-s with OX catalyst
Kettering University	3 cyl. 659 cc Daihatsu turbocharged EFI 4-stroke with TWC cat.
Michigan Technological Univ.	Honda VFR 791 cc EFI V-4 4-stroke with TWC catalyst
Minnesota State Univ. (Mankato)	500 cc liquid-cooled Polaris 2-stroke with TWC catalyst
Univ. at Buffalo (SUNY)	500 cc turbocharged EFI 4-stroke with TWC and OX catalysts
Univ. of Alaska, Fairbanks	3 cyl. 953 cc Suzuki turbocharged EFI 4-s with EGR and TWC
University of Alberta	Suzuki GSXR 600 cc EFI 4-stroke with TWC catalyst
University of Idaho	BMW K-75 750 cc 4-stroke with Bosch LE EFI and catalyst
University of Kansas	3 cyl. 929 cc Honda CBZ 4-stroke with OEM catalyst and sec. air
University of Waterloo	500 cc liquid-cooled Polaris carb. 2-stroke with dual-bed catalyst and secondary air injection
University of Wyoming	Kawasaki 617 cc 4-stroke engine with catalyst
Reference snowmobile	2001 Polaris Sport Touring, 550 cc 2-stroke

Rules of the emissions competition required teams to achieve a minimum of a 25% reduction in CO, and a 50% reduction in HC+NOx, as compared to current production snowmobiles. Failing either criterion would result in a zero score for the emissions event. To provide a reference point, a 2001 Polaris Sport Touring snowmobile equipped with a 550 cc 2-stroke engine was selected from the Flagg Ranch fleet of sleds. It was tested first to provide a reference, baseline emissions level for the competition.

III. TEST EQUIPMENT

A. Mobile Emissions Laboratory

A mobile laboratory (truck) was outfitted with laboratory-grade instrumentation for measurement of 2-stroke and 4-stroke engine HC, CO, CO_2, NO_x, and O_2 using raw exhaust gas sampling. See Figure 1. Major equipment required for the mobile laboratory emissions bench included:

- 2-stroke HC, HFID (SwRI design)
- 4-stroke HC, HFID (Rosemount 402)
- High CO, NDIR (Horiba)
- Low CO, NDIR (Rosemount 868)
- CO_2, NDIR (Rosemount 868)
- NOx, CLA (Rosemount 955)
- O_2 (Rosemount CM1EA)
- Raw exhaust sampling system with heated (375°F) sample lines
- Chart recorder
- Calibration gases, NIST traceable

FIGURE 1. EMISSIONS BENCH

B. Dynojet Dynamometer

A Dynojet snowmobile chassis dynamometer was used to load snowmobile engines during emissions testing. See Figure 2. The dynamometer uses air-cooled eddy current absorbers, and can achieve a maximum load of 867 lb-ft. The dyno can perform closed-loop control on mph (track speed) or torque, or on engine rpm. A dedicated computer provides dynamometer control and data acquisition. Readouts are available for engine speed, sled speed, and torque.

FIGURE 2. DYNOJET DYNAMOMETER

Prior to testing, each snowmobile's stock suspension was removed and replaced with an adjustable dynamometer carriage that provided connection to the dyno from the rear belt sprocket, plus a means of adjusting belt tension. This is shown in Figure 3. Two dyno carriages were used at the event so that the next sled to be tested could be fitted with a carriage while the preceding sled was being tested.

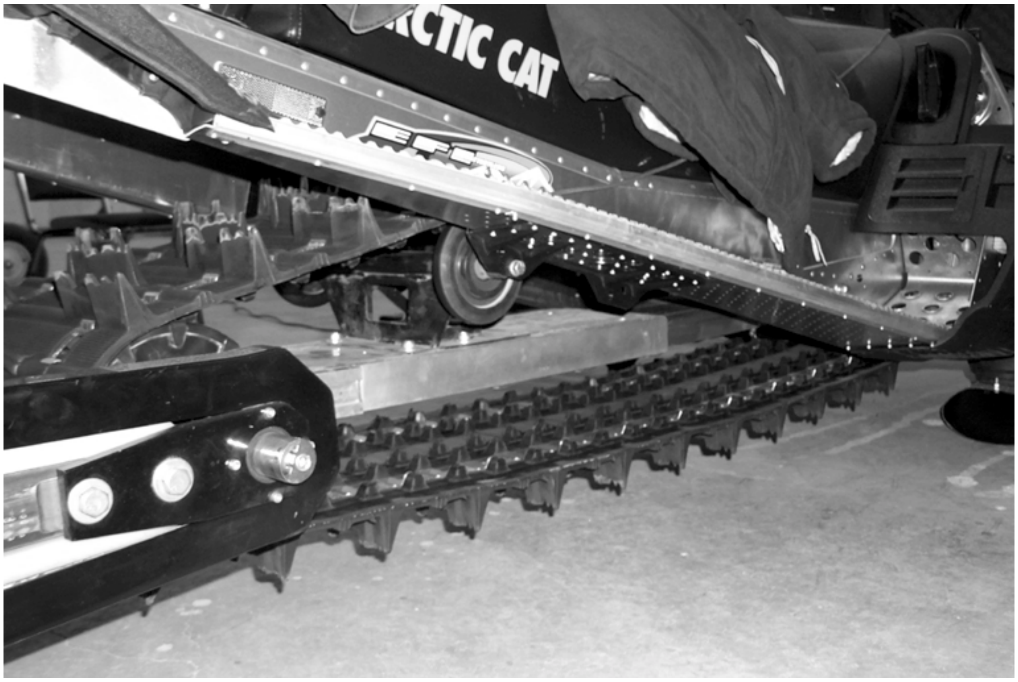

FIGURE 3. DYNAMOMETER CARRIAGE

C. Exhaust Gas Sampling Probe

Each sled in the competition was required to be fitted with an exhaust gas sampling probe, in accordance with probe design and installation specifications, as described below.

Sample probe. (1) The sample probe shall be a straight, closed end, stainless steel, multi-hole probe made from ¼ in. OD stainless steel tubing. The wall thickness of the probe shall not be greater than 0.10 cm. (2) The probe shall have nine 1/16 in. holes. The spacing of the radial planes for each hole in the probe must be such that they cover approximately equal cross-sectional areas of the exhaust duct. The nine holes shall be drilled in a spiral pattern with an angular spacing between adjacent holes of approximately 120 degrees. This results in a spiral pattern with three triads of holes aligned along the length of the probe.

Probes were installed in engine exhaust systems using stainless-steel Swagelok fittings, in accordance with the following requirements:

1. For systems without aftertreatment, the probe must be placed after the point at which the exhaust from all cylinders is well mixed, a minimum of five pipe diameters downstream of the last ‘Y’ connection.

2. For systems with air injection or aftertreatment, the probe must be placed a minimum of five pipe diameters downstream of the converter outlet.

3. For all systems, the probe must be placed a minimum of 12 in. upstream of the end of the exhaust pipe.

D. Fuel Flow Measurement

Accurate fuel flow data are required to make brake-specific emissions measurements. Three different fuel flow measurement techniques were provided to accommodate the range of sled fuel supply systems. For sleds with a single fuel supply line to the engine (no return line), we used a small fuel flow meter (Max, model 213-186) that was inserted into the fuel line. For sleds with a separate return line, fuel consumption was measured gravimetrically. Teams with this type of fuel system were required to provide a second sled fuel tank/pump system that could be mounted on a digital scale. Valves were installed in the sled's fuel system so it could be switched between the on-board and the external fuel supply tanks. We also provided a day tank system which could be used for sleds with a fuel return line.

E. Supplemental Engine Cooling System

Supplemental cooling is required for snowmobile engine operation on either a stand or a chassis-type dynamometer. Fan-cooled engines were tested with two supplemental cooling fans directed onto the engine with the cover open. For liquid-cooled engines, we constructed an external heat exchanger system consisting of a small automotive radiator with an electric fan. See Figure 4. Teams made provisions to hook up to this external system for operation on the dynamometer. Liquid-cooled sleds were configured with supply and return lines available in their cooling systems with 1 in. male hose-barbed fittings for connection to the external system. Shutoff ball valves were placed immediately before the hose fittings to minimize loss of coolant when switching over. The external system was filled with Arctic Cat premixed coolant.

FIGURE 4. SUPPLEMENTAL COOLING

After connection to the external cooling system, sleds were run for several minutes to purge all air bubbles from the system. The radiator was then topped up and the radiator pressure cap was installed. Engine water temperature control was provided by the engine thermostat.

IV. TEST PROCEDURE

To facilitate a comparison of CSC 2001 emission data with previously generated laboratory data, we planned to use the five-mode snowmobile test cycle, as developed by SwRI for the International Snowmobile Manufacturers Association (ISMA). This cycle is shown in Table 2 for reference.

TABLE 2. ISMA/SWRI SNOWMOBILE ENGINE TEST CYCLE

Mode	1	2	3	4	5
Speed, %	100	85	75	65	Idle
Torque, %	100	51	33	19	0
Wt. Factor, %	12	27	25	31	5

Test modes are run in order, from highest to lowest speed. One hundred percent engine speed is defined as the maximum steady engine speed in snowmobile operation. Torque values are specified as a percent of the maximum (WOT) torque observed at 100 percent speed in mode 1.

While experiments with the baseline 2-stroke sled showed good control under most conditions, mode 4 was problematic due to the low applied load and variability in snowmobile clutch engagement. The test cycle was modified by eliminating mode 4, and proportionally reassigning its mode weight to the remaining modes. The modified cycle is shown in Table 3. Teams determined maximum steady speeds (sled mph and engine rpm) at WOT after arriving at Flagg Ranch. These values were used to set up test modes on the dynamometer for individual sleds.

TABLE 3. MODIFIED SNOWMOBILE ENGINE TEST CYCLE

Mode	1	2	3	4
Speed, %	100	85	75	Idle
Torque, %	100	51	33	0
Wt. Factor, %	18	39	36	7

V. FUELS AND LUBRICANTS

Teams were allowed a choice of three fuels: premium gasoline, premium E10 (10% ethanol), or regular E10 (10% ethanol). Samples of the three fuels were analyzed, and results are summarized in Table 4.

TABLE 4. FUELS ANALYSES

	Regular E10	Premium	Premium E10
Specific Gravity at 50F, g/ml	0.740	0.717	0.719
Specific Gravity at 30F, g/ml	0.748	0.726	not determined
Carbon, mass %	83.10	84.83	81.96
Hydrogen, mass %	13.15	14.49	14.48
Oxygen, mass %	3.75	n/a	3.56

Fuels used during the competition are identified in the summary table of emission results. Teams were free to use their choice of lubricant.

VI. EMISSION RESULTS

Snowmobiles were emissions tested in a maintenance shed at Flagg Ranch. After replacing the sled's track with a dynamometer carriage, it was installed on the snowmobile chassis dynamometer and prepared for testing. Fuel flow measurement equipment was connected to the sled's fuel system, and the supplemental cooling system was connected for liquid-cooled sleds. Supplemental blowers were positioned to direct air into the open engine compartment. The heated sample line was connected to the probe to extract a sample of raw exhaust gas.

Sleds were first warmed up to normal operating temperature, and then run at WOT at the declared maximum sled speed. Dynamometer load was then adjusted to obtain the team's declared maximum engine speed to establish Mode 1 conditions. Test modes were then run in order, from Mode 1 to 4. Emission results were calculated following procedures specified for nonroad spark-ignited engines (40 CFR Part 90).

Two sleds were unable to complete emissions testing. CSU's engine suffered a mechanical failure, and Michigan Tech's drive chain failed. Teams from Alaska and Kansas were unable to get their engines running properly in time for emissions testing. Emission results for the nine teams completing testing, plus the reference Polaris sled, are summarized in Table 5. Emission reductions achieved by the student sleds, as compared to the reference sled, are summarized in Table 6. Detailed modal results for each sled, including carbon balance calculated air/fuel ratios, are attached.

TABLE 5. EMISSION RESULTS

Sled	Engine Type	Rated Speed, rpm	Track Power, kW	Fuel	Weighted Emissions, g/kW-hr			
					HC	CO	NO_x	$HC+NO_x$
Flagg Ranch, Baseline	2-Stroke	7,200	9.73	Reg. E10	177.9	1524	2.32	180.2
Clarkson Univ.	4-Stroke	10,000	39.67	Premium	19.1	736	0.05	19.2
Colorado Mines	4-Stroke	9,000	3.14	Prem. E10	30.8	948	3.63	34.4
Kettering Univ.	4-Stroke	7,100	28.22	Reg. E10	4.2	323	0.85	5.1
Minn. State, Mankato	2-Stroke	7,800	34.84	Prem. E10	35.4	387	2.16	37.6
Univ. at Buffalo, SUNY	4-Stroke	6,100	7.13	Premium	5.6	267	0.22	5.8
Univ. of Alberta	4-Stroke	8,200	20.13	Premium	58.5	840	1.13	59.6
Univ. of Idaho	4-Stroke	7,200	13.12	Reg. E10	28.3	625	1.40	29.7
Univ. of Waterloo	2-Stroke	7,000	18.76	Prem. E10	65.9	617	0.63	66.5
Univ. of Wyoming	4-Stroke	2,500	1.48	Prem. E10	70.2	599	22.88	93.1

TABLE 6. EMISSION REDUCTIONS COMPARED TO BASELINE SLED

Sled	CO, % Reduction	HC, % Reduction	NOx, % Reduction	HC+NOx, % Reduction
Clarkson Univ.	52	89	98	89
Colorado Mines	38	83	-56*	81
Kettering Univ.	79	98	63	97
Minn. State, Mankato	75	80	7	79
Univ. at Buffalo, SUNY	82	97	91	97
Univ. of Alberta	45	67	51	67
Univ. of Idaho	59	84	40	84
Univ. of Waterloo	60	63	73	63
Univ. of Wyoming	61	61	-886	48
* Negative numbers indicate an increase in emissions				

The Flagg Ranch sled CO value is higher than those observed with laboratory-tested snowmobile engines, likely due to the lower barometric pressure at Flagg Ranch (typically 23-24 in. Hg), and the use of a one size larger jet for improved operation and durability.

Two 2-stroke powered sleds from Waterloo and Mankato completed emission testing. Both maintained reasonably good power while also significantly reducing emissions, compared to the reference sled. Both teams employed slightly leaner calibrations and catalysts to reduce HC and CO emissions.

The seven 4-stroke engines tested came from a variety of sources ranging from motorcycle engines (Mines, Idaho, Alberta, and Clarkson) to automotive engines (Kettering), to ATV engines (Buffalo and Wyoming). Sled emission results were affected by a number of factors. Since emissions were determined on a brake-specific (work) basis, power level is significant. Sleds from Mines and Wyoming were able to deliver only limited amounts of power to the dynamometer. This illustrates the importance of proper clutching, since the engines were clearly able to produce more power than their drivetrains could deliver to their belts. Thus, lower power levels, all other things being equal, will result in higher brake-specific emission levels.

It should be emphasized that power levels reported in Table 5 are indicated (uncorrected) power, as measured from the <u>sled track</u>. Laboratory snowmobile emissions are determined using an engine dynamometer with power measured at the <u>engine crankshaft</u>. Since the typical snowmobile loses on the order of 50 percent of its power in track and drivetrain losses, chassis dynamometer measured brake-specific emission levels will be significantly higher than engine dynamometer measured emissions.

Another major factor influencing 4-stroke engine results was air-fuel calibration. While 4-strokes avoid the scavenging losses of the 2-stroke design, most engines were still operating rich at one or more modes, resulting in relatively high CO emissions. The Wyoming sled, on the other hand, ran very lean at Modes 2 and 3, which created high NO_x levels.

The two snowmobiles with the best emissions were better calibrated and had better emission reduction technology. Buffalo's sled ran at or near stoichiometric, except during Mode 3 which was rich. This, coupled with a dual-brick TWC+OX catalyst system, provided the lowest overall emissions, narrowly beating Kettering who placed second in the emissions event. The Kettering sled employed a 3-cylinder Daihatsu automotive engine, complete with factory calibration and catalyst system, as designed for Japanese automotive emission standards. This "drop-in" solution performed very well, although it ran very rich at Mode 1 (WOT), as is typical for an automotive calibration.

Emissions from all sleds could have been further improved if more time had been available for engine and drivetrain calibration. Results are still very impressive given the limited time and budget available to these teams.

VII. SUMMARY AND CONCLUSIONS

Fourteen student teams entered snowmobiles in the 2001 SAE Clean Snowmobile Challenge. Competition objectives called for reducing noise and exhaust emissions while maintaining respectable performance and handling characteristics. Equipment was assembled on-site at Jackson Hole to provide for brake-specific emissions measurement using a snowmobile chassis dynamometer and a modified version of the ISMA snowmobile engine test cycle.

Both 2- and 4-stroke solutions were entered in the competition; many incorporated catalytic aftertreatment in their designs. The Waterloo 2-stroke sled that placed first overall in the competition was able to reduce its HC+NOx emissions to 66.5 g/kW-h, and its CO emissions to 617 g/kW-h. The sled with the lowest emissions (Buffalo), employed a 4-stroke engine with both three-way and oxidation catalysts. It achieved emission levels of 5.8 g/kW-h HC+NOx and 267 g/kW-h CO, which represents a 97% and an 82% reduction respectively, from the reference sled.

While none of these designs constitute a production-ready solution, they clearly show that there are alternatives to the conventional, high-emitting 2-stroke, which can provide acceptable performance in a touring sled.

Prepared by:	Approved by:
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Manager, Certification, Audit, and Compliance	Director
Department of Emissions Research	Department of Emissions Research

DEPARTMENT OF EMISSIONS RESEARCH
AUTOMOTIVE PRODUCTS AND EMISSIONS RESEARCH DIVISION

ATTACHMENTS

SNOWMOBILE MODAL EMISSION RESULTS

FLAGG RANCH - BASELINE

Test Number: Flagg   Date: 3/24/01   Time: 04:00 PM
Engine: 2-Stroke   Fuel: Regular E10   Displacement: 550 cc
Rated Speed: 7200 rpm   Full Throttle Power: 9.73 kW
Weighted Ave. Measured Power: 4.00 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	1379	15101	11	0.18	141.7	1552	1.17
2	85	51	776	7174	13	0.39	185.1	1711	3.06
3	75	33	338	1453	6.0	0.36	199.5	858	3.56
4	IDLE	0	548	746.6	0.6	0.07			

Weighted Hourly Mass Emissions	g/hr		
	711	6091	9
Weighted Brake Specific Mass Emissions	g/kWhr		
	177.9	1524	2.32

Engine:2-Stroke Run #:Flagg	**Average Mode 1**	**Average Mode 2**	**Average Mode 3**	**Average Mode 4**
TRACK SPEED [mph]:	70	50	32	0
DYNO TORQUE [lb-ft]:	32	20	12	0.0
DYNO SPEED [rpm]:	2118	1513	968	0
DYNO POWER [kW]	9.73	4.19	1.69	0.0
FUEL FLOW [g/hr]:	12967	7728	3493	1310
FUEL FLOW [lb/hr]:	29.7	17.7	8.0	3.00
NOx HUMID. ADJ. FACTOR [KH]:	1.00	1.00	1.00	1.00
DRY-WET CONV. FACTOR [K]:	0.91	0.90	0.89	0.94
AIR/FUEL RATIO:	9.3	10.6	13.3	12.5
CO, %[wet]:	10.09	7.37	2.88	4.08
CO2, %[wet]:	5.54	7.05	9.74	4.33
HC, ppmC[wet]:	18600	16100	13500	60500
NOx, ppm[wet]:	46	80	72.7	18.8
O2, %[wet]	3.04	3.14	4.61	9.78
F Factor	1.218	1.218	1.218	1.218
BSFC, g/kW-hr	1332	1843	2064	

COLORADO MINES

Test Number: Colorado Mines Date: 3/25/01 Time: 04:45 PM
Engine: 4-Stroke Fuel: Premium E10 Displacement: 600 cc
Rated Speed: 9000 rpm Full Throttle Power: 3.14 kW
Weighted Ave. Measured Power: 1.26 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	112	3944	14	0.18	35.7	1257	4.52
2	85	51	24	582	3	0.39	19.6	466	2.15
3	75	33	21	621	2.7	0.36	37.5	1093	4.70
4	IDLE	0	18	441.7	0.0	0.07			

Weighted Hourly Mass Emissions	g/hr		
	39	1191	5
Weighted Brake Specific Mass Emissions	g/kWhr		
	30.8	948	3.63

Engine: 4-Stroke Run #: Colorado Mines	**Average Mode 1**	**Average Mode 2**	**Average Mode 3**	**Average Mode 4**
TRACK SPEED [mph]:	40	25	15	0
DYNO TORQUE [lb-ft]:	18	12	9	0.0
DYNO SPEED [rpm]:	1210	756	454	0
DYNO POWER [kW]	3.1	1.2	0.6	0.0
FUEL FLOW [g/hr]:	7794	4078	3580	680
FUEL FLOW [lb/hr]:	17.9	9.3	8.2	1.56
NOx HUMID. ADJ. FACTOR [KH]:	0.858	0.86	0.86	0.86
DRY-WET CONV. FACTOR [K]:	0.880	0.88	0.88	0.88
AIR/FUEL RATIO:	12.5	14.5	14.3	11.7
CO, %[wet]:	3.66	0.94	1.15	4.91
CO2, %[wet]:	10.74	12.30	12.18	9.93
HC, ppmC[wet]:	2100	800	800	4100
NOx, ppm[wet]:	93	31	35.2	1.8
O2, %[wet]	0.04	0.15	1.13	0.22
F Factor	1.219	1.219	1.219	1.219
BSFC, g/kW-hr	2485	3263	6297	

WATERLOO

Test Number: Waterloo
Engine: 2-Stroke
Rated Speed: 7000 rpm

Date: 3/26/01
Fuel: Premium E10

Time: 05:00 PM
Displacement: 500 cc
Full Throttle Power: 18.75 kW
Weighted Ave. Measured Power: 7.40 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	1671	17539	6	0.18	89.1	935	0.31
2	85	51	365	3408	4	0.39	50.0	466	0.51
3	75	33	123	169	6.1	0.36	37.7	52	1.86
4	IDLE	0	2	260.2	0.1	0.07			

Weighted Hourly Mass Emissions	g/hr		
	488	4565	5
Weighted Brake Specific Mass Emissions	g/kWhr		
	65.9	617	0.63

Engine: 2-Stroke Run #: Waterloo	Average Mode 1	Average Mode 2	Average Mode 3	Average Mode 4
TRACK SPEED [mph]:	70	46	32	0
DYNO TORQUE [lb-ft]:	62	37	24	0.0
DYNO SPEED [rpm]:	2118	1392	968	0
DYNO POWER [kW]	18.8	7.3	3.3	0.0
FUEL FLOW [g/hr]:	14844	5676	3536	2008
FUEL FLOW [lb/hr]:	34.0	13.0	8.1	4.60
NOx HUMID. ADJ. FACTOR [KH]:	1.00	1.00	1.00	1.00
DRY-WET CONV. FACTOR [K]:	0.91	0.89	0.89	0.88
AIR/FUEL RATIO:	9.1	12.5	16.3	14.8
CO, %[wet]:	10.35	4.30	0.29	0.84
CO2, %[wet]:	5.34	9.22	11.34	12.21
HC, ppmC[wet]:	19900	9300	4200	100
NOx, ppm[wet]:	21	29	62.5	2.6
O2, %[wet]	2.23	1.43	3.39	0.44
F Factor	1.206	1.206	1.206	1.206
BSFC, g/kW-hr	792	776	1080	

MANKATO

Test Number: Mankato
Engine: 2-Stroke
Rated Speed: 7800 rpm

Date: 3/27/01
Fuel: Premium E10

Time: 10:30 PM
Displacement: 500 cc
Full Throttle Power: 34.84 kW
Weighted Ave. Measured Power: 14.2 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	2313	24455	18	0.18	66.4	702	0.52
2	85	51	190	2316	29	0.39	13.8	168	2.10
3	75	33	33	150	44.9	0.36	4.7	21	6.30
4	IDLE	0	13	2135.2	0.0	0.07			

Weighted Hourly Mass Emissions	g/hr		
	504	5509	31
Weighted. Brake Specific Mass Emissions	g/kWhr		
	35.4	387	2.16

Engine: 2-Stroke Run #: Mankato	**Average Mode 1**	**Average Mode 2**	**Average Mode 3**	**Average Mode 4**
TRACK SPEED [mph]:	75	52	42	0
DYNO TORQUE [lb-ft]:	108	62	40	0.0
DYNO SPEED [rpm]:	2269	1573	1271	0
DYNO POWER [kW]	34.8	13.8	7.1	0.0
FUEL FLOW [g/hr]:	23226	8033	5108	2576
FUEL FLOW [lb/hr]:	53.2	18.4	11.7	5.90
NOx HUMID. ADJ. FACTOR [KH]:	1.00	1.00	1.00	1.00
DRY-WET CONV. FACTOR [K]:	0.90	0.88	0.89	0.88
AIR/FUEL RATIO:	9.1	13.5	16.1	11.2
CO, %[wet]:	9.32	1.99	0.18	6.36
CO2, %[wet]:	6.77	11.62	11.95	9.05
HC, ppmC[wet]:	17800	3300	800	800
NOx, ppm[wet]:	42	152	323.4	0.9
O2, %[wet]	0.60	0.19	2.39	0.02
F Factor	1.193	1.193	1.193	1.193
BSFC, g/kW-hr	667	582	717	

BUFFALO

Test Number: Buffalo
Engine: 4-Stroke
Rated Speed: 6100 rpm

Date: 3/27/01
Fuel: Premium

Time: 09:30 PM
Displacement: 498 cc
Full Throttle Power: 7.13 kW
Weighted Ave. Measured Power: 2.8 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	8	159	3	0.18	1.1	22	0.42
2	85	51	12	504	0	0.39	4.4	180	0.04
3	75	33	26	1455	0.1	0.36	20.9	1164	0.08
4	IDLE	0	5	93.1	0.0	0.07			

Weighted Hourly Mass Emissions	**g/hr**		
	16	755	1
Weighted Brake Specific Mass Emissions	**g/kWhr**		
	5.6	267	0.22

Engine: 4-Stroke Run #: Buffalo	**Average Mode 1**	**Average Mode 2**	**Average Mode 3**	**Average Mode 4**
TRACK SPEED [mph]:	55	35	22	0
DYNO TORQUE [lb-ft]:	30	19	13	0.0
DYNO SPEED [rpm]:	1664	1059	666	0
DYNO POWER [kW]	7.1	2.8	1.2	0.0
FUEL FLOW [g/hr]:	5154	2734	2008	350
FUEL FLOW [lb/hr]:	11.4	6.0	4.4	0.77
NOx HUMID. ADJ. FACTOR [KH]:	0.796	0.80	0.80	0.80
DRY-WET CONV. FACTOR [K]:	0.879	0.88	0.89	0.89
AIR/FUEL RATIO:	14.8	14.5	12.1	14.7
CO, %[wet]:	0.20	1.21	5.25	1.70
CO2, %[wet]:	12.99	11.98	9.18	11.04
HC, ppmC[wet]:	200	600	1900	1800
NOx, ppm[wet]:	29	2	2.7	0.9
O2, %[wet]	0.31	0.72	2.21	1.53
F Factor	1.188	1.188	1.188	1.188
BSFC, g/kW-hr	723	975	1607	

IDAHO

Test Number: Idaho   Date: 3/25/01   Time: 11:55 PM
Engine: 4-Stroke   Fuel: Regular E10   Displacement: 750 cc
Rated Speed: 7200 rpm   Full Throttle Power: 13.12 kW
Weighted Ave. Measured Power: 4.7 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	171	7427	15	0.18	13.0	566	1.16
2	85	51	152	2526	5	0.39	35.3	588	1.20
3	75	33	109	1497	5.0	0.36	63.0	868	2.88
4	IDLE	0	42	697.0	0.1	0.07			

Weighted Hourly Mass Emissions	g/hr		
	132	2910	7
Weighted Brake Specific Mass Emissions	g/kWhr		
	28.3	625	1.40

Engine: 4-Stroke Run #: Idaho	Average Mode 1	Average Mode 2	Average Mode 3	Average Mode 4
TRACK SPEED [mph]:	60	36	21	0
DYNO TORQUE [lb-ft]:	51	28	19	0.0
DYNO SPEED [rpm]:	1815	1089	635	0
DYNO POWER [kW]	13.1	4.3	1.7	0.0
FUEL FLOW [g/hr]:	10347	5938	3842	830
FUEL FLOW [lb/hr]:	23.7	13.6	8.8	1.90
NOx HUMID. ADJ. FACTOR [KH]:	0.870	0.87	0.87	0.87
DRY-WET CONV. FACTOR [K]:	0.879	0.88	0.88	0.88
AIR/FUEL RATIO:	11.1	12.4	12.4	10.2
CO, %[wet]:	5.60	3.13	2.87	6.98
CO2, %[wet]:	9.89	11.35	11.56	8.95
HC, ppmC[wet]:	2600	3800	4200	8400
NOx, ppm[wet]:	80	45	66.6	4.4
O2, %[wet]	0.04	0.06	0.95	0.40
F Factor	1.216	1.216	1.216	1.216
BSFC, g/kW-hr	789	1382	2228	

ALBERTA

Test Number: Alberta
Engine: 4-Stroke
Rated Speed: 8200 rpm

Date: 3/26/01
Fuel: Premium

Time: 08:00 PM
Displacement: 600 cc
Full Throttle Power: 20.13 kW
Weighted Ave. Measured Power: 8.05 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	777	8327	27	0.18	38.6	414	1.35
2	85	51	343	7528	9	0.39	45.5	998	1.19
3	75	33	523	6253	1.9	0.36	126.5	1512	0.45
4	IDLE	0	136	1134.2	0.4	0.07			

Weighted Hourly Mass Emissions	**g/hr**		
	471	6765	9
Weighted Brake Specific Mass Emissions	**g/kWhr**		
	58.5	840	1.13

Engine: 4-Stroke Run #: Alberta	**Average Mode 1**	**Average Mode 2**	**Average Mode 3**	**Average Mode 4**
TRACK SPEED [mph]:	55	36	30	0
DYNO TORQUE [lb-ft]:	85	49	32	0.0
DYNO SPEED [rpm]:	1664	1089	908	0
DYNO POWER [kW]	20.1	7.5	4.1	0.0
FUEL FLOW [g/hr]:	11567	7258	5806	2449
FUEL FLOW [lb/hr]:	25.5	16.0	12.8	5.40
NOx HUMID. ADJ. FACTOR [KH]:	0.808	0.81	0.81	0.81
DRY-WET CONV. FACTOR [K]:	0.883	0.89	0.89	0.89
AIR/FUEL RATIO:	10.6	9.3	8.6	13.3
CO, %[wet]:	5.84	9.03	10.01	3.18
CO2, %[wet]:	9.43	7.71	7.06	9.91
HC, ppmC[wet]:	11000	8300	16900	7700
NOx, ppm[wet]:	143	81	22.3	8.9
O2, %[wet]	0.02	0.02	0.96	1.51
F Factor	1.205	1.205	1.205	1.205
BSFC, g/kW-hr	575	962	1404	

CLARKSON

Test Number: Clarkson
Date: 3/26/01
Time: 06:00 PM
Engine: 4-Stroke
Fuel: Premium
Displacement: 929 cc
Rated Speed: 10,000 rpm
Full Throttle Power: 39.67 kW
Weighted Ave. Measured Power: 15.2 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	367	16573	1	0.18	9.2	418	0.03
2	85	51	343	10109	1	0.39	23.1	682	0.05
3	75	33	253	11858	0.6	0.36	39.9	1865	0.09
4	IDLE	0	1	2.3	0.0	0.07			

Weighted Hourly Mass Emissions	g/hr		
	291	11,195	1
Weighted Brake Specific Mass Emissions	g/kWhr		
	19.1	736	0.05

Engine: 4-Stroke Run #: Clarkson	Average Mode 1	Average Mode 2	Average Mode 3	Average Mode 4
TRACK SPEED [mph]:	75	49	34	0
DYNO TORQUE [lb-ft]:	123	70	44	0.0
DYNO SPEED [rpm]:	2269	1482	1029	0
DYNO POWER [kW]	39.7	14.8	6.4	0.0
FUEL FLOW [g/hr]:	18576	10800	11265	781
FUEL FLOW [lb/hr]:	41.0	23.8	24.8	1.72
NOx HUMID. ADJ. FACTOR [KH]:	0.839	0.84	0.84	0.84
DRY-WET CONV. FACTOR [K]:	0.877	0.88	0.88	0.89
AIR/FUEL RATIO:	9.7	9.2	8.6	16.2
CO, %[wet]:	7.61	8.33	9.73	0.02
CO2, %[wet]:	9.27	9.07	8.51	12.17
HC, ppmC[wet]:	3400	5700	4200	100
NOx, ppm[wet]:	4	4	3.5	0.4
O2, %[wet]	0.02	0.02	0.90	0.22
F Factor	1.208	1.208	1.208	1.208
BSFC, g/kW-hr	468	729	1772	

KETTERING

Test Number: Kettering
Engine: 4-Stroke
Rated Speed: 7100 rpm

Date: 3/26/01
Fuel: Regular E10

Time: 11:15 PM
Displacement: 659 cc
Full Throttle Power: 28.22 kW
Weighted Ave. Measured Power: 12.4 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	185	18195	10	0.18	6.6	645	0.35
2	85	51	42	1852	21	0.39	3.3	145	1.61
3	75	33	7	53	2.0	0.36	1.0	8	0.31
4	IDLE	0	1	2.0	0.0	0.07			

Weighted Hourly Mass Emissions	g/hr		
	52	4017	11
Weighted Brake Specific Mass Emissions	g/kWhr		
	4.2	323	0.85

Engine: 4-Stroke Run #: Kettering	**Average Mode 1**	**Average Mode 2**	**Average Mode 3**	**Average Mode 4**
TRACK SPEED [mph]:	71	55	44	0
DYNO TORQUE [lb-ft]:	93	54	35	0.0
DYNO SPEED [rpm]:	2148	1664	1331	0
DYNO POWER [kW]	28.2	12.8	6.6	0.0
FUEL FLOW [g/hr]:	16247	7341	4451	363
FUEL FLOW [lb/hr]:	37.2	16.8	10.2	0.83
NOx HUMID. ADJ. FACTOR [KH]:	0.834	0.83	0.83	0.83
DRY-WET CONV. FACTOR [K]:	0.887	0.88	0.88	0.88
AIR/FUEL RATIO:	9.2	13.5	14.6	15.3
CO, %[wet]:	9.74	1.75	0.08	0.04
CO2, %[wet]:	7.61	12.14	13.31	12.79
HC, ppmC[wet]:	2000	800	200	200
NOx, ppm[wet]:	38	142	21.9	0.1
O2, %[wet]	0.13	0.11	1.00	0.88
F Factor	1.202	1.202	1.202	1.202
BSFC, g/kW-hr	576	573	678	

WYOMING

Test Number: Wyoming
Date: 3/25/01
Time: 04:45 PM
Engine: 4-Stroke
Fuel: Premium E10
Displacement: 617 cc
Rated Speed: 2500 rpm
Full Throttle Power: 1.48 kW
Weighted Ave. Measured Power: 0.52 kW

Mode	Speed % of Rated	Torque % of Mode 1 Maximum	Mass Emissions, g/hr			Mode Weight Factor	Modal Brake Specific Emissions, g/kWh		
			HC	CO	NOx		HC	CO	NOx
1	100	100	41	1216	24	0.18	28.1	825	16.48
2	85	51	19	55	14	0.39	34.6	100	25.50
3	75	33	54	56	5.2	0.36	541.3	567	53.05
4	IDLE	0	29	693.7	0.9	0.07			

Weighted Hourly Mass Emissions	g/hr		
	36	309	12
Weighted Brake Specific Mass Emissions	g/kWhr		
	70.2	599	22.88

Engine: 4-Stroke Run #: Wyoming	Average Mode 1	Average Mode 2	Average Mode 3	Average Mode 4
TRACK SPEED [mph]:	41	21	5	0
DYNO TORQUE [lb-ft]:	8	6	5	0.0
DYNO SPEED [rpm]:	1240	635	151	0
DYNO POWER [kW]	1.5	0.6	0.1	0.0
FUEL FLOW [g/hr]:	3968	2689	1962	892
FUEL FLOW [lb/hr]:	9.1	6.2	4.5	2.04
NOx HUMID. ADJ. FACTOR [KH]:	0.853	0.85	0.85	0.85
DRY-WET CONV. FACTOR [K]:	0.884	0.90	0.90	0.88
AIR/FUEL RATIO:	14.1	17.6	18.7	11.1
CO, %[wet]:	2.03	0.11	0.15	6.06
CO2, %[wet]:	11.22	11.05	10.18	9.15
HC, ppmC[wet]:	1400	800	2900	5200
NOx, ppm[wet]:	290	208	100.4	54.0
O2, %[wet]	0.88	2.91	5.37	0.44
F Factor	1.211	1.211	1.211	1.211
BSFC, g/kW-hr	2690	4870	19826	